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# The Waldmeier Effect in Sunspot Cycles

B. B. Karak and A. R. Choudhuri

Department of Physics, Indian Institute of Science, Bangalore, India

**Summary.** We discuss two aspects of the Waldmeier Effect, namely (1) the rise times of sunspot cycles are anti-correlated to their strengths (WE1) and (2) the rates of rise of the cycles are correlated to their strengths (WE2). From analysis of four different data sets we conclude that both WE1 and WE2 exist in all the data sets. We study these effects theoretically by introducing suitable stochastic fluctuations in our regular solar dynamo model.

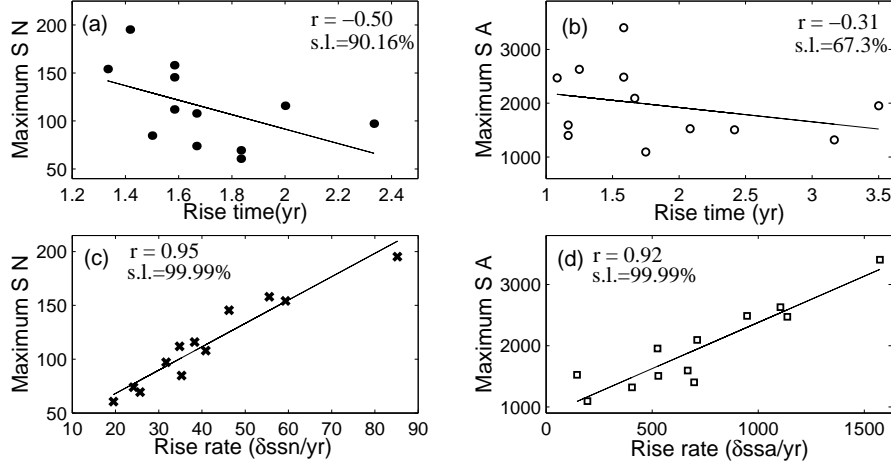
## 1 Introduction

The Waldmeier effect is an important feature of solar cycles. However, with “Waldmeier effect” two different measures are meant by different authors, causing confusion in the literature. The first is the observation that the rise times of sunspot cycles are anti-correlated to their strengths (i.e. the stronger cycles have shorter rise times). The second is that the rates of rise of the cycles are correlated to their strengths (i.e. the stronger cycles rise faster). Let us refer to these somewhat different correlations as WE1 and WE2.

Hathaway et al. (2002) found evidence for WE1 in both the Zürich sunspot numbers and the group sunspot numbers, whereas Dikpati et al. (2008b) claim that this effect does not exist in sunspot area data. We believe that this discrepancy was caused mainly by not defining the rise time carefully. A new sunspot cycle sometimes begins before the end of the previous cycle, making it difficult to ascertain exactly when the cycle began. Some cycles have plateau-like maxima with multiple peaks, so that it is difficult to say when the rising phase ended. We analyze the observational data by carefully defining the rise time and the rate of rise. A theoretical study to understand this effect is planned in addition. The details are presented in Karak & Choudhuri (2010).

## 2 Observational study

We have studied four different data sets: (1) Wolf sunspot numbers (cycles 12–23), (2) group sunspot numbers (cycles 12–23), (3) sunspot area data (cycles 12–23) and (4) 10.7 cm radio flux (available only for the last 5 cycles). All data sets have been smoothed by a Gaussian filter with a FWHM of 1 yr. For a cycle with amplitude  $P$ , we take the rise time to be the time during which the activity level changes from  $0.2P$  to  $0.8P$ . The rise time defined in this way has a good anti-correlation with the cycle amplitude for all the data sets, the correlation coefficients and the significance levels for the four data types being: (1)  $-0.50$  and 90.16% for sunspot numbers; (2)  $-0.42$  and 82.12% for group sunspots; (3)  $-0.31$  and 67.3% for sunspot areas; and (4)  $-0.33$  and 41% for 10.7 cm radio flux. The results for sunspot numbers and sunspot areas are shown in panels (a) and (b) of Fig. 1. These results are very sensitive to the averaging bin size. If we average the data with a FWHM of 2-yr instead of 1 yr, we get much higher value. Also if we calculate the rise time differently by taking the end of rise phase to be the time when the cycle reaches a strength of  $0.7P$  or  $0.9P$  (rather than  $0.8P$ ), then the correlation coefficients change also, having a value of about  $-0.7$  in one case comparable to what Hathaway et al. (2002) reported.



**Fig. 1.** Observational evidences for WE1 (upper row) and WE2 (lower row). Upper row shows scatter diagrams plotting the peak values of (a) sunspot number and (b) sunspot area against rise times. Lower row shows scatter diagrams plotting the peak values of (c) sunspot number and (d) sunspot area against rise rates.

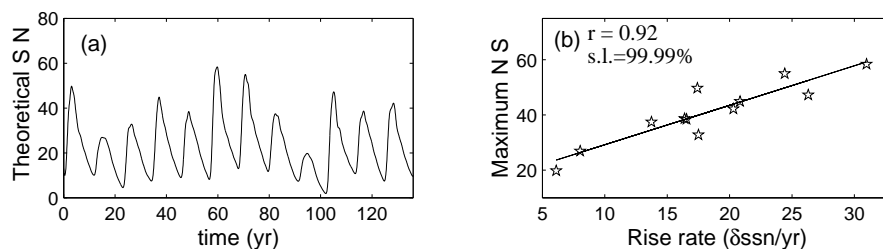
We also study the second Waldmeier effect WE2 in all four data sets. We calculate the rate of rise by determining the slope between two points at a separation of one year, with the first point one year after the sunspot mini-

imum. We find strong correlation between the rates of rise and the amplitudes of the sunspot cycles consistent with earlier results (Cameron & Schussler 2008). Results for sunspot number and sunspot area are shown in panels (c) and (d) of Fig. 1.

We conclude that there is evidence for both WE1 and WE2 in different kinds of data sets.

### 3 Preliminary theoretical results

We plan to carry out a theoretical study based on our flux transport dynamo model (Nandy & Choudhuri 2002, Chatterjee et al. 2004) to explain the Waldmeier effect. We believe that the fluctuations in the Babcock–Leighton process of poloidal field generation is the main source of irregularities in solar cycles (Choudhuri et al. 2007; Jiang et al. 2007; Choudhuri & Karak 2009). Variations in meridional circulation are likely to introduce additional irregularities. Preliminary results of WE2 are shown in Fig. 2.



**Fig. 2.** (a) Theoretical sunspot number. (b) Scatter diagram plotting peak sunspot numbers against rise rates.

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